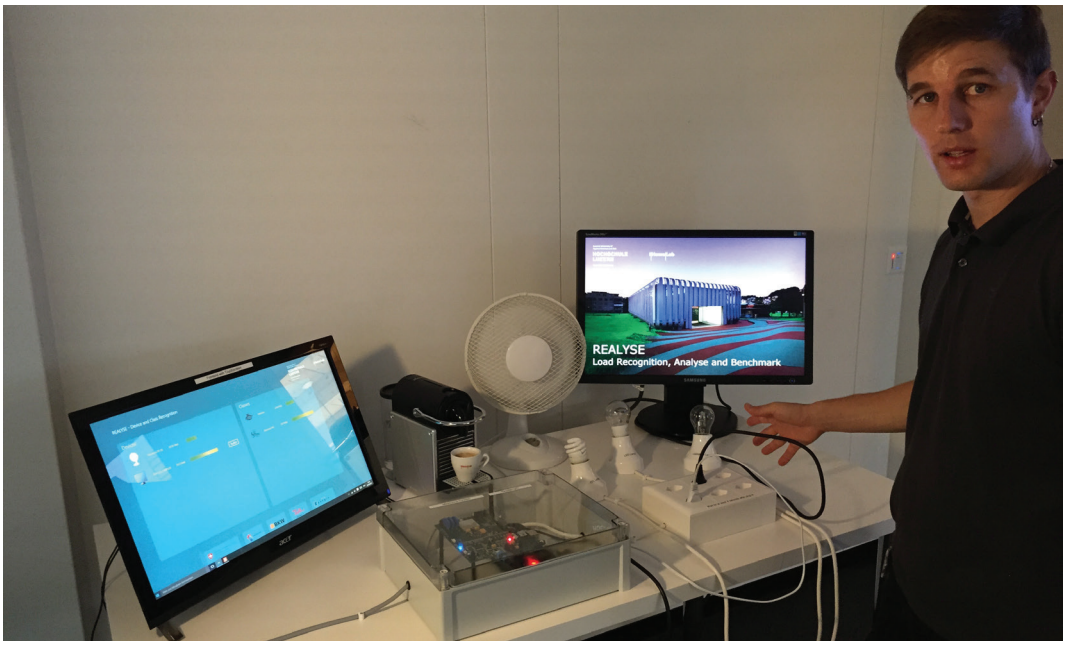
A measurement system that recognizes (almost) all electrical appliances

Most people have no idea how much electricity their daily activities at home consume—but it would be an important prerequisite for conscientious use of energy. Researchers at the iHomeLab at Lucerne University have developed an analysis system that from the total power of a household (total load curve), can detect any electrical equipment that is switched on and can measure the individual energy consumption in real time.



iHomeLab Project Leader Lukas Kaufmann with the demonstrator NIALM system: There are two devices turned on (right screen and fan); on the screen on the left is displayed the class to which the two devices belong, also the current power consumption. Photo: B. Vogel

Dr. Benedikt Vogel, commissioned by the Swiss Federal Office of Energy (SFOE)

Those traveling by car today know at all times how much fuel is being consumed. All it takes is a glance at the fuel gauge next to the speedometer to give the driver a good feel for the car's energy consumption and the fuel cost—a feeling that can tip the balance towards choosing a more economical model the next time you buy a car; or when the opportunity arises, the motivation to try out an Eco-Drive course.

It isn't the same with electricity consumption. Here most people lack a sense of the quantity of electricity consumed—electrical appliances usually carry no usage guage. Consequently people often lack knowledge of how much power their razor, desk lamp

Technical report about the results of a research project in the field of Electricity Technologies, which is financially supported by the Swiss Federal Office of Energy.

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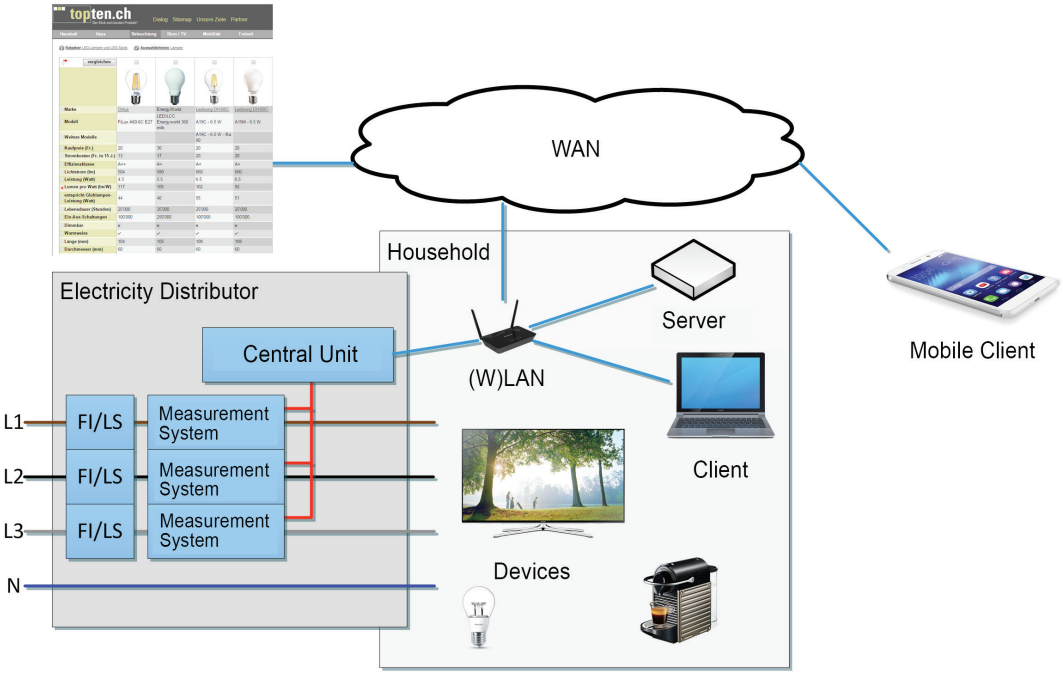
or blender, for example, consume. Under the buzzwords "Smart Home" and "Smart Metering," technologies have tried for several years to compensate for this shortcoming. Such novel devices are intended to measure household energy consumption and thus also enable appliances or utilities to be "intelligently" networked and regulated.

NIALM technology as the basis

For this reason in the early 1990s the Massachusetts Institute of Technology (Cambridge / USA) developed a new concept. The basic idea was to be able to recognize each individual electrical device from the overall energy load curve of a household. This technology is called non-contact load recognition by consumers (in english referred to as NIALM—non-intrusive appliance load monitoring). The NIALM technology is able to measure power consumption of each electrical appliance in a household without having to equip each one with a meter.

The vision of an inexpensive energy measurement infrastructure for households has since attracted the attention of various research groups, one of which works at the University of Lucerne in Horw, just outside Lucerne. There anyone interested in iHomeLab can watch a demonstration of a newly developed NIALM system and try it out. Lukas Kaufmann, a research associate at iHomeLab, stands in front of a table on which rests six electricity consuming devices found in every household: a power-saving lamp, an LED lamp, a light bulb, a screen, a fan and a Nespresso machine. "If you turn the electrical appliances on and off individually," says Lukas Kaufmann to visitors, "our system will display a few seconds later, the type of device it is and how much power it consumes."



System Overview: In household electrical distribution, a measuring system is installed per secured circuit. Thus the elctricity usage of all connected devices in the home will be measured and data will be analyzed by a central unit. The central unit is connected to the local network (LAN / WLAN). This way, this data is sent to a server in the local network. This prepares the analyzed data for display on a client (laptop, tablet, smartphone) and brings over the Internet from the Website topten.ch, the data that will enable the household efficiency to be compared with other electrical devices in the same class. Illustration: HSLU

Device class and device type

We make an example out of the test: we switch on the power-saving lamp. It takes a few seconds. Then on the screen display appears: 'Philips Tornado 8 W'. The consumption of the lamp is 7.7 watts (W). Next in line is the fan, which turns and blows us in the face. A little later we read on the screen: 'Intertronic RT-23' with a current consumption of 18.7 W. After switching it on, the Nespresso machine makes it to 1096.6 W, but only for a few seconds, until the water is heated. A bit later when we prepare the espresso, the machine needs 1139.6 W. After a few seconds, the cup is full - and the power consumption drops to zero.

The NIALM system that detects the electrical appliances and measures their consumption fits in a space the size of a shoebox. Is the system smart enough to detect a foreign electrical appliance? A visitor puts his cell phone charger in the wall socket next to the NIALM system. Consumption: 6.2 W. Device class: small consumer. "Our demonstrator detects the device class, it realizes that it is a device with a power supply and low energy consumption," says Lukas Kaufmann, "whether it is an iPhone 6, it does not recognize." The demonstration model recognizes the device only if it has been previously trained on it. "The demonstrator model of iHomeLab has been trained on the six electricity consuming devices that are on the table. Such training, however, is in principle feasible for all standard electrical appliances, and in only a few seconds.

Search for economical alternatives

Lukas Kaufmann is the technical project leader of iHomeLab NIALM. Next to him, Prof. Alexander Klapproth, director of iHomeLab, takes care of developing the visionary building technologies that he can showcase to an interested public. For Klapproth, the NIALM system brings fascinating applications into reach. "Our NIALM system measures not only consumption, but we can also identify the appropriate device class. This opens the possibility of proposing to users economical alternative equipment and offering them concrete savings potential."

To illustrate an example, Alexander Klapproth points to a home refrigerator: if the NIALM system identifies a home fridge with a consumption of 211 kWh / year, then it may search in a database for refrigeration appliances that consume less than 211 kWh / year. The user then learns in seconds if he could save power with alternative devices and what savings effects come with those devices. "You can very easily determine with our system, which electrical appliances in a household are

Device Class	Example
Electricity-saving lamp	Energy saving bulb, LED lights
Bulb	Bulb, Halogen lamp
Large resistive energy consumer	Stove top, Electric oven
Coffee Machine	
Inductive energy user	Washing machine, Blender
Cooling device	
Small energy user	Cellular charging device
Electronics without PFC	Laptop, Ink-jet printer
Electronics with PFC	Computer, Television

PFC (power correction factor filter) serve to smooth phase shifted and non-sinusoidal currents so that no disturbances occur in supply network.

These nine classes of devices are recognized by the NIALM system of the Lucerne University and don't require the device to be specially trained. Table: B. Vogel / HSLU

no longer up to date with respect to energy efficiency," says Alexander Klapproth. "In the same way, you could of course also identify in office buildings the power-hungry devices and at the same time calculate potential cost savings." In order to achieve this goal, the researchers want to link individual Lucerner NIALM systems with the database topten.ch, which classifies a broad range of commercial electrical appliances according to their energy efficiency and other measures.

Limits of detectability

Other applications are also conceivable for the Lucerne researchers: detecting home appliances that are unnecessarily in operation; or as a warning system, if, say, someone forgets to turn off a stove. The NIALM system also shows which electrical devices in a household are used and when. "On this basis we can identify patterns of activity. This will open new applications that are useful, for older people living alone, for example, because they provide extra security," explains Alexander Klapproth.

The iHomeLab demonstrator project points to the potential of the technology; but it also shows its associated difficulties. The demonstrator is, according to its developers, capable of assigning electrical devices in a household to nine classes of devices (e.g. coffee machine) even if it is 'untrained.' If the NIALM system is trained to recognize an electrical device, it can recognize the specific type of device (Nespresso capsule machine, filter coffee machine) usually, but not always. The recognition is not fine enough to also reliably identify in each case the type of device, which is more or less relevant depending on the application. Even more research efforts are needed to eradicate such typical teething problems for new technologies and to convert the demonstrator into a marketable product. Within the current framework of the Swiss Federal Office of Energy funded projects, the iHomeLab demonstrator shall be enabled to compare recognized electrical devices in real-time with the electrical appliances listed in the topten.ch database. The researchers want to achieve this objective by the end of November 2015.

Pilot plant in a real environment

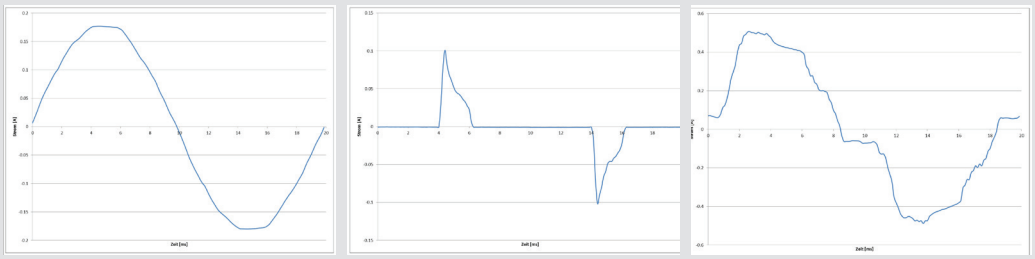
In a follow-up project, the scientists want to use and test the NIALM system in a real environment. The intention is to equip a property consisting of several apartments with the system, as Dr. Rainer Kyburz, Head of Energy Efficiency Research on iHomeLab states: "We want to evaluate the detection rate, but also gain experience of how the users interact with the system and what benefits they pull from it. "The iHomeLab is currently looking for a partner in the real estate industry who wishes to provide a suitable location to install the system." It is also important in the end that the NIALM system does not itself become power-hungry. The demonstrator currently requires 500 mW. For the Lucerne researchers, the target energy consumption is 200 mW.

» For further information on the project, please contact Roland Brüniger (roland.brueniger[at]r-brueniger-ag.ch), head of the SFOE-research program Electricity Technologies.
» For more technical papers on research, pilot, demonstration and flagship projects in the field of electricity technologies, see www.bfe.admin.ch/CT/strom

The fingerprint of electrical appliances

Each electrically operated device in an apartment - lamp, electric stove, computer, etc. - takes from the electricity network as much power as it needs to operate. If one wants to determine power consumption, one must install on each device a meter. In the case of Ecowizz Geroco (Martigny / VS), for example, this measuring device is a 'Smart Plug', or in the case of the West Swiss start-up eSmart, it is a measuring chip. The iHomeLab at Lucerne University takes a different approach: To measure current, it uses a measurement system based on the NIALM technology. This measurement system requires installation of a meter per secured circuit (i.e. per circuit breaker). The device measures once per second during a 20 millisecond period with 150 individual measurements of the current flow in this circuit and sends the measurement data to a distribution box mounted on the central unit. This leads to analysis of the data from all devices measured. This analysis is then communicated to external bodies and the system may additionally perform other functions.

But how does the NIALM measuring device gauge out of the total current, at the time of measurement, which electrical devices in the corresponding circuit are switched on? The first indication is provided by an abrupt change in the total current, or in the calculated total output. Should the total power increase by 1200 watts, it guesses that possibly a burner of the electric stove was turned on. If the overall performance goes back by 60 watts, it guesses that an old light bulb may have been switched off. Such jumps in the strength (amplitude) of the total current or total power supply deliver the first hints as to which devices are currently turned on; however if two devices are switched on or off at exactly the same time, or if there was no on / off operation, an identification is not possible.



Electric stoves and bulbs are so called resistive loads; they can be "seen" only on the strength of the current used. The situation is different with a vacuum cleaner or hair dryer, which are operated by an electric motor. Electric motors are called inductive loads. They relate - like resistive loads - a current that can be graphically represented as a sinusoidal curve, however, the electricity use is identified by a phase shift (the sinusoidal curve of electricity use shows a time delay compared to the sinusoidal curve of the alternating voltage). So the device can use two characteristics, strength of current and phase shift, to detect a vacuum cleaner or a hair dryer.

A third group of electrical household appliances (eg. laptops and televisions) have switch mode power supplies. These include inverters that convert the alternating current from the outlet into direct current. Inverters and other electrical components that are installed in switch-mode-power-supply devices leave behind specific traces in power usage. The reference curve of current is here no longer sinusoidal, but shows an irregular course with

pronounced peaks ('loading bumps'). Switch-mode- power-supplied devices can therefore be recognized by the very individual curves they form (and also of course by the strenth of current). The automated analysis of such irregular curves requires large computational resources. In order to reduce the amount of data and to speed up computer evaluation, the Lucerner scientists approximate the irregular curves as the sum of sinusoidal waves with different amplitude and frequency (accuracy: up to the 11th harmonic). Thus, the reference curve of current is not completely adequately depicted, but any curve can be represented as a comparatively compact data set.

With its reference curve of current, every appliance leaves an 'electrical fingerprint' so to speak. The NIALM system developed by iHomeLab evaluates these fingerprints using a sophisticated analysis program (algorithm) that can assign the connected devices to one of nine classes of device. If the NIALM system is to not only recognize the device class, but also the respective device type, the NIALM system must be 'trained'. This is done by the person who during the first measurement, matches the observed reference curve of current to the correct device type; whenever the NIALM system detects this reference curve of current in the future, it assigns it to the assigned device. BV

Manifold approaches to measure consumption

There are already a number of products that enable an analysis of electricity consumption. "However, most of them are based on the evaluation of smart meter data, which typically have a temporal resolution of 15 minutes," says Klapproth. They typically attempt to identify a device based solely on the power cosumed while switching the device switch on / off and, if necessary, via contextual information (e.g. time of day) (e.g. PlotWatt / USA, Bidgely / USA, fluids / F, The Energy Detective / USA). On the way, however, only large electricity consuming devices can be detected.

A product of the Belgian company Smappee (www.smappee.com), which is sold for 199 EUR, goes one step further. The device also detects the electrical appliances in the household based on the power used during ON / OFF operations. However, the measurement is carried out with a higher temporal resolution, more than every 15 minutes. "While this improves the detection accuracy with respect to the smart meter approach, it can still only detect larger energy consuming devices, this is in contrast to our system," says iHomeLab Director Prof. Alexander Klapproth.

There are further products that take similar aproaches to the iHomeLab NIALM system, according to Klapproth, however, they require complicated and expensive electronic measuring equipment (e.g. LoadIQ / USA, Qualisteo Wattseeker / F, Smart pulse / F). These are designed for use in industry and too expensive for the residential sector. BV

Swiss Federal Office of Energy (SFOE)
Mühlestrasse 4, CH- 3063 Ittigen, Postal address: CH-3003 Bern
Phone +41 (0)58 462 56 11, Fax +41 (0)58 463 25 00
cleantech@bfe.admin.ch, www.bfe.admin.ch

11/2015