Supplementary Information

The published papers related to EMS in SDOL database number 357,030, and that in IEL Online number 26,767. This huge amount of information has been screened according to the following principles: (1) Articles reported the quantitative results of energy conservation; and (2) Energy saving effects were obtained from the experiments at practical sites. After screening, 100 cases reported by 73 papers, related to EMS applications, would be chosen to demonstrate the energy saving effect by applying the EMS, as shown in Table S1:

Table S1. Energy savings by EMS.

Year	Case	Main effects
1984	EMS at a meat packing facility [1]	Payback rate ~2 years
1985	EMS in the food and kindred products industries [1]	Payback rate ~1.8 years
1985	EMS in warehouses [2]	5.5% refrigerating system energy saving 16% whole site electricity cut down
1985	EMS in a fish-processing plant [3]	Payback rate <3 years
1985	EMS learns to ripen bananas [4]	Payback rate <0.25 year
1985	Large distributed EMS in a magnetic tape plant [5]	15% whole factory energy saving Payback rate ~1.2 years
1985	EMS for HVAC and lighting equipment monitoring [6]	15% light system energy saving 5% air conditioning system energy saving
1986	Industrial energy accounting and control systems [1]	10%–20% whole site energy saving
1987	Multi-microprocessor-based EMS for an air flow heating system [7]	50% air flow heating system energy saving
1987	Soft-Systems Model of Energy Management and Checklists for Energy Managers [8]	5%–10% whole site energy saving
1987	Building energy management system, BEMS [9]	20%–30% HVAC system energy saving
1990	Ohio Edison company EMS upgrade [10]	Payback rate ~3 years
1998	EMS for cogeneration system [11]	36% whole plant energy saving
1998	Implementation of EMS for an integrated steel plant [12]	Payback rate ~1 year
1998	Optimal steam turbine network operation by EMS [13]	17.35% whole plant energy saving
1998	EMS for electrical energy conservation in Saudi Arabia [14]	25% whole site energy saving
1999	EMS for fuel saving in central heating installation [15]	30% energy saving of heating system
1999	A large scale energy reporting system for the process industry [16]	23.49% whole plant energy saving
2000	EMS installed at Indian Petrochemicals Corporation Limited (IPCL) Nagathone Gas Cracker complex [17]	35% whole plant energy saving
2000	Joint management of energy and environment [18]	35% whole plant energy saving
2000	EMS integrated into the quality system of Grimstad Konservesfabrik (GK) company [19]	23.8% whole company energy saving
2000	EMS installed at the factory of Kjøttcentralen co. [20]	Payback rate ~1.8 years

Table S1. *Cont.*

Year	Case	Main effects
2003	Direct or indirect feedback of information for home EMS [21]	5%–15% house energy saving
2004	EMS integrated design for sustainable buildings [22]	35%–50% energy savings at a new commercial building
2004	Office equipment power management [23]	2% energy saving of the whole office
2004	EMS for HVAC system at a shopping center [24]	22% energy saving in HVAC system
2005	EMS for complex buildings [25]	5.3% energy saving for HVAC system, 0.8% annual electricity consumption saving
2006	EMS for HVAC system optimization [25]	6.74% energy saving for the year-round consumption
2006	Energy-consumption information system for home energy conservation [26]	9% energy saving at home
2007	City level energy management [27]	6%–9% energy saving
2008	Decision support development for EMS [28]	6%–10% energy saving of a hospital
2008	EMS with deployed wireless sensor network [29]	10%–15% energy saving of whole plant
2008	An intelligent demand site management system at the European sites [30]	1%–4% energy saving of whole plant
2008	Enthalpy estimation for thermal comfort control and energy saving in air conditioning system [31]	13% energy saving of air conditioner
2009	EMS for Linyun Iron and Steel Group [31]	11% energy saving of factory
2009	Intelligent decision support tool for building energy saving [32]	9% energy saving of buildings
2009	Adaptive network based fuzzy controller for HVAC system [33]	35% energy saving in HVAC system
2010	Neural temperature control and management system in subtropical Hong Kong [34]	12.9% VAV system energy saving
2010	EMS to assess the potential of different control strategies in HVAC systems [35]	1% energy savings of HVAC system
2010	Daylight linking lighting control system [36]	Payback rate ~8.8–12.7 years
2011	EMS integrated with facility monitoring and control systems (FMCS) [37]	23.2% energy saving of a factory
2011	Home EMS based on automatic meter reading [38]	1.7%–1.9% energy saving at home
2011	Convenience stores air conditioner energy saving by wireless sensor network [39]	11%–34.5% energy saving of air conditioner
2011	Energy conservation in commercial buildings in Saudi Arabia [40]	30% energy saving in HVAC system
2011	Energy saving potential and strategies for electric lighting [41]	50% lighting system energy saving
2012	Cooperative energy management [42]	23.9% building HVAC system energy saving
2012	EMS for joint management according to the ISO 50001 Standard [43]	20% energy saving of 300 test plants in average by PDCA management

Table S1. *Cont.*

Year	Case	Main effects
2012	Occupancy detection for lighting system control [44]	12% lighting system energy saving
2012	Household EMS development [45]	5%–15% air conditioning energy saving
2012	EMS for fine chemistry industrial park [46]	2% energy saving of the factory
2012	Online energy management for industrial sites [47]	2%–5% energy saving of utility assets on industrial sites
2013	EMS based on variable water flow [48]	31.5% energy saving of deep-mine cooling system
2013	Data mining project performed by EMS [49]	4%–7% energy saving of a factory
2013	Web based GUI and applications for smart gadgets [50]	28.55% air conditioning energy saving
2013	Statistical analysis of energy consumption data for energy conservation [51]	12.4% energy saving of industrial processes
2013	Putting energy management on the strategic agenda in energy-intensive process industries [52]	13% energy saving of test factories
2013	A versatile EMS for large integrated cooling systems [53]	33.3% cooling system energy saving
2013	Home EMS [54]	3% energy saving of a residential building
2013	Home EMS for assessing overall lifecycle [55]	1.5% energy saving
2013	EMS for foundry industries [56]	7.5% factory energy saving
2013	Occupancy detection based control for HVAC system [57]	23% energy saving of HVAC system
2013	Sleeping mode control of air conditioner based on thermal comfort and energy management [58]	10% energy saving of air conditioner
2014	Energy audit of an industrial site [59]	Payback rate ~1.6 years
2014	EMS development for adjustable luminance control at each location of the building [60]	27% lighting system energy saving
2014	Integration strategies between daylight and electric lighting and strategies based on the occupancy of spaces [61]	32% lighting system energy saving
2014	Continuous feedback on households' electricity consumption [62]	5%–10% electricity saving
2014	Energy management in green building [63]	15% Lamp energy saving 10% heating energy saving
2014	Real-time scheduling discipline to coordinate the activation/deactivation of a set of loads [64]	8% energy saving of whole plant
2014	Smart meters and load controllers in an occupied office building [65]	5.2% energy saving of whole plant
2014	Optimization of HVAC system [66]	32% HVAC system energy saving
2014	Lighting control technologies in commercial buildings [67]	15% lighting system energy saving
2014	Dimmer control lighting system energy saving [68]	35.1%–41.5% lighting system energy saving
2014	Integrated energy optimization for the cement industry [69]	7% energy saving of the whole factory

Table S1. *Cont.*

Year	Case	Main effects
2014	Behavioral pattern for air conditioning energy saving [70]	31.9% energy saving of air conditioners
2014	Building automation and control system [61]	17%–32% lighting system energy saving
2014	Energy management in Swedish iron and steel industry [71]	9.7% energy saving of whole plant
2014	EMS for university campus [72]	6% energy saving of whole campus

Reported cases in Table S1 could be separated as energy saving controls for single facility and whole site. The cases of single facility comprise lighting system, HVAC system, air conditioner, office equipment, IT equipment and deep-mine cooling system, *etc.* The cases of whole site contain the residential building, commercial building, complex building, factory and University campus, *etc*.

Key Energy Management Functions of EMS

In Table S1, there are 73 published papers. Among them, the cases of whole site adopting the EMS for energy saving management are 57, and that of single facility are 43. Through reviewing these cases, 12 represented function groups are clustered as following:

(1) Graphic tool: Including Full graph/Graphic trend analysis/Web based GUI/Regional man-machine support/Supervisory control/Monitoring/Comprehensive monitoring and targeting functionality/ Performance indicators, *etc*. The main function of this tool is to present the energy usage information graphically for enhancing the managing efficiency.
(2) Optimization: Including Optimized start and stop/Optimized scheduling/Optimized setting/Steam Boiler optimization/Chiller optimization, *etc*. The energy usage conservation of whole site or single facility would be practiced by the optimized calculation.
(3) Site specific strategies: Including the specific control functions and strategies of various sites or facilities.
(4) Scheduling: Including Scheduled algorithms/Scheduled start and stop/Smart scheduling *etc*. The energy saving management would be carried out by the scheduling plans of various facilities.
(5) Demand response control: Including Peak load control/Pricing methods/Demand limiting/Day and night setback/Financial appraisal/Off load algorithms/Duty cycle/Demand forecast *etc*. The main functions are to adjust the peak-time power demand and manage the electricity usage between daytime and nighttime for reducing the electric charge and managing the energy usage.
(6) Thermal comfort control: Including Enthalpy control/Ventilation and recirculation/PMV control/ Economizer/Reheated Coil Reset, *etc*. The main function is to exercise the energy saving control for the facilities, mainly for the HVAC system, according to the Predictive Mean Vote or the Thermal comfort level.
(7) Modeling: Including State estimation/Energy consumption modeling/Model assisted control/ Wireless sensor network assisted modeling/ Model/ Simulation assisted control/Integration with energy modeling software and enterprise business databases, *etc*. The energy saving control of

the whole site may be carried out through the distributed sensors, collected information, built model, predicted controlling goals and optimized control.

(8) Occupancy detection: Including Occupancy detection based control/Sleep mode of air conditioner/Smart lighting system control, *etc*. The energy saving control of the facility would be practiced by detecting the users' state.

(9) Energy audit: Including Joint management/ISO standard based management/PDCA cycle/Perform an audit of mass and energy flow/A profitable energy conservation and environmental improvements list/Performance indicators, *etc*. This function would carry out the cooperated management of energy and resource, and the audit according to the ISO standards. The Performance index and the managing improvement list could be provided according to the auditing results.

(10) Dimmer control: Including Adjustable luminance control/Optimized lighting system arrangement, *etc*. The optimization of luminance adjustment for lightening facilities would be practiced.

(11) Decision support tool: Including Relational data bases/Targeting/Behavior pattern/System database management/Data base management/Expert system, *etc.* The Expert system is based on the data collection for EMS, building the database, seeking for the correlation, determining the users' behavior for assisting the energy manager to make the decision.

(12) Big data analysis: Including Data mining/System database management/Security management/Regional accounting and logging, *etc*. The function could collect huge data for EMS, analyze and mine the data, manage the data systematically, exercise the data encryption for the cloud, manage and login for the local accounts.

Based on the 12 represented functions mentioned above, the main functions of EMS for effective energy saving would be identified according to the application amount of the 100 EMS application cases, as shown in Figure S1.

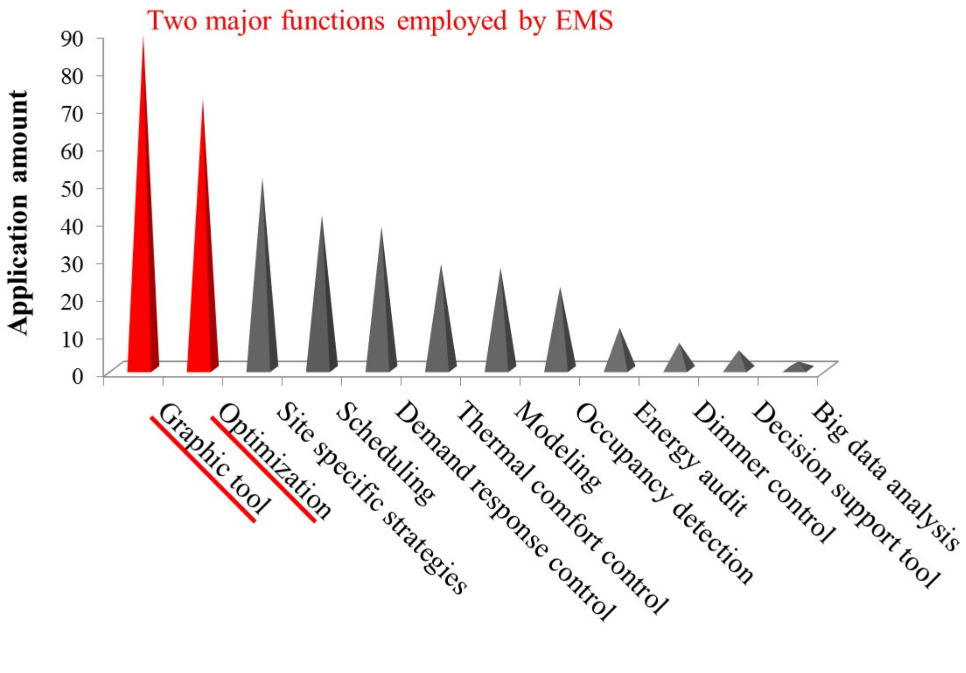

Figure S1. Among 100 EMS cases, two major EMS functions are identified according to the application amounts.

In Figure S1, the largest application amount of the EMS functions is the Graphic tool, which presents the energy usage information graphically for enhancing the managing efficiency. Another main EMS function is Optimization. There are almost 80% of cases adopting the notion of Optimization for energy saving management. The other one is Site specific strategies. According to the various cases, this function may utilize various speed drivers, flow control, or other specific strategies for energy saving management. Nevertheless, this function is close to the customized energy management, and needs to be modified depending on the facilities in the site.

On the basis of energy saving effects larger than 20%, the main EMS functions for effective energy saving would be identified again depending on the application amount in the above EMS cases with high percentage of energy usage, as shown in Figure S2.

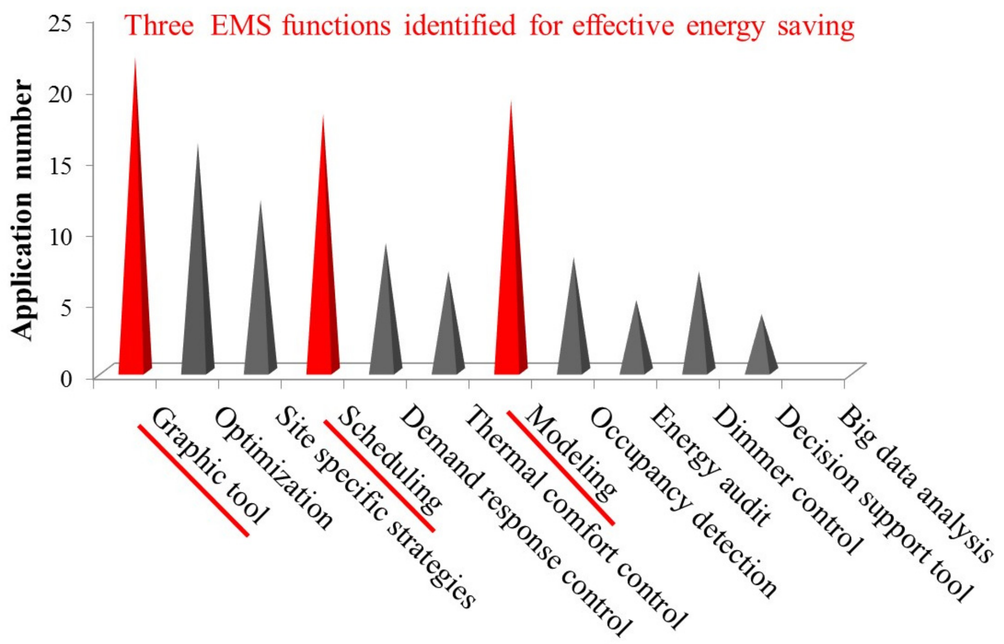

Figure S2. For EMS cases with energy saving effects > 20%, the application numbers of 12 functions are analyzed to identify main functions with high energy saving rate.

In Figure S2, the functions of the graphic tool, scheduling and modeling are the three major functions with the energy saving rates larger than 20%. Comparing the functions in Figures S1 and S2, one can find that the graphic tool is the most fundamental and important EMS function, and the optimization is another one. For various places and facilities, the function of optimization could determine the better setting point for a facility, suggest the better and achievable energy saving control targets for a site, and present the critical effect during the energy saving process. Scheduling is the control functions practiced on the sites and facilities, following the strategies provided by the optimization function. The function of modeling is to connect all the sensors, collect all the information from communication facilities, and build the mathematic model, which is the calculating basis of optimization function.

In summary, the graphic tool, scheduling, optimization and modeling are the four important tools to apply the EMS. In this paper, the developed functions described above would be adopted in the cloud energy management service for carrying out the evolution of EMS for effective energy saving.

Actual Energy Measurement Data of Sites

There were 35 iEN demo sites, including factories, complex buildings and residential buildings, under the test of energy saving rate from 2012 to 2013. The iEN was also deployed for energy saving control on the additional 12 lighting systems and 8 air conditioning systems. Due to the confidentiality agreements signed by Chunghwa Telecom and the demo sites, which iEN is installed, not all the measured energy usage information are allowed to be released. Furthermore, the measured energy usage information are recorded every minute continually since 2011, and these are in the scale of big data. Hence, this paper presented several measured energy usage data of the 35 iEN demo sites for demonstrating the variation of sites as shown in Figures S3–S6.

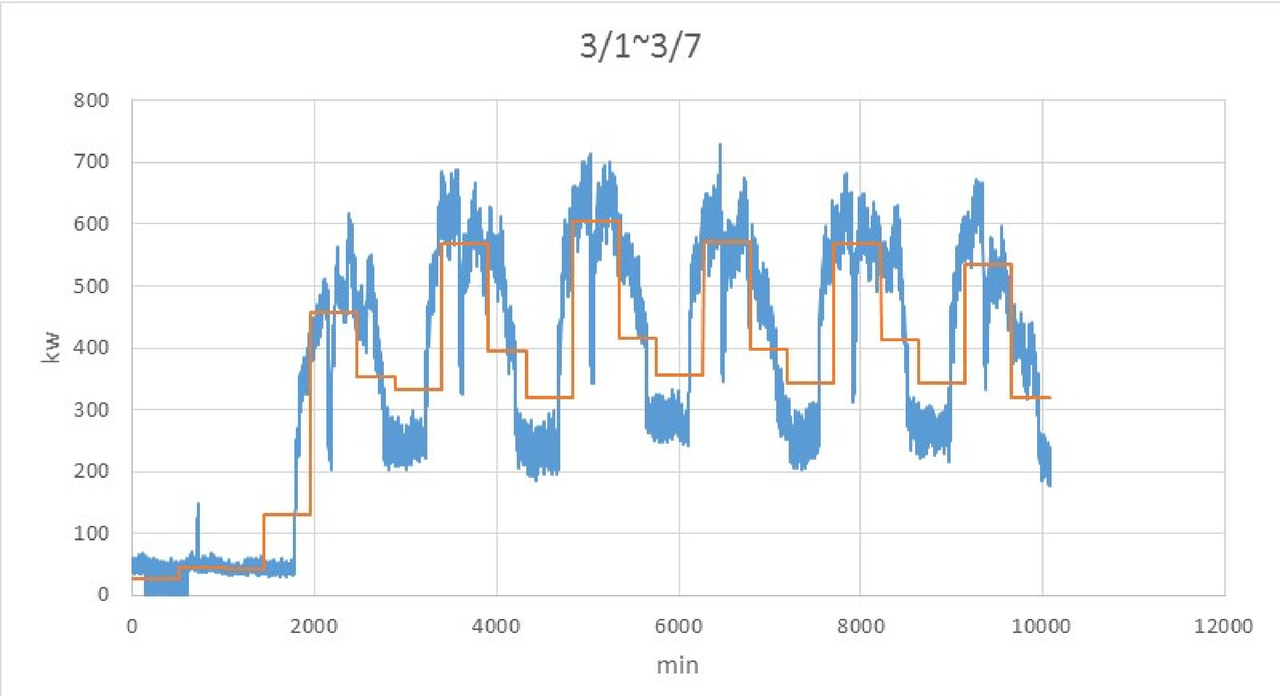

Figure S3. Measured energy usage data of iEN demo site: International bearing company.

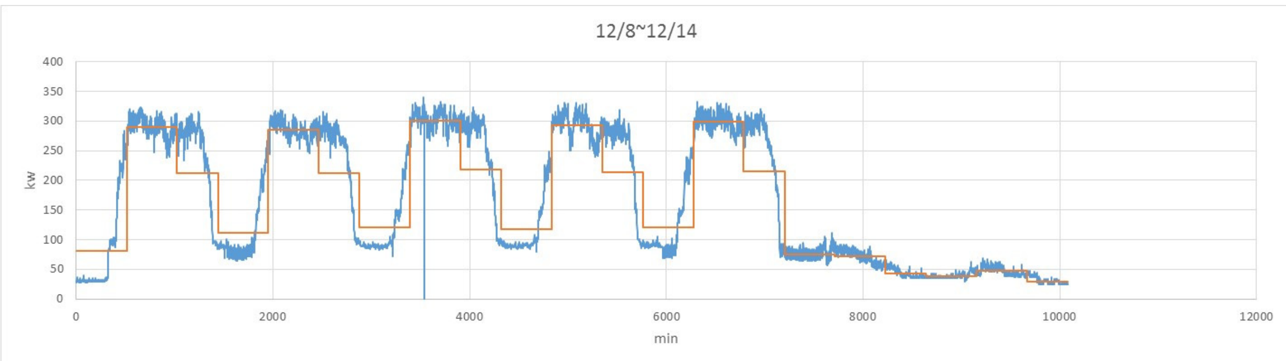

Figure S4. Measured energy usage data of iEN demo site: Chemical factory.

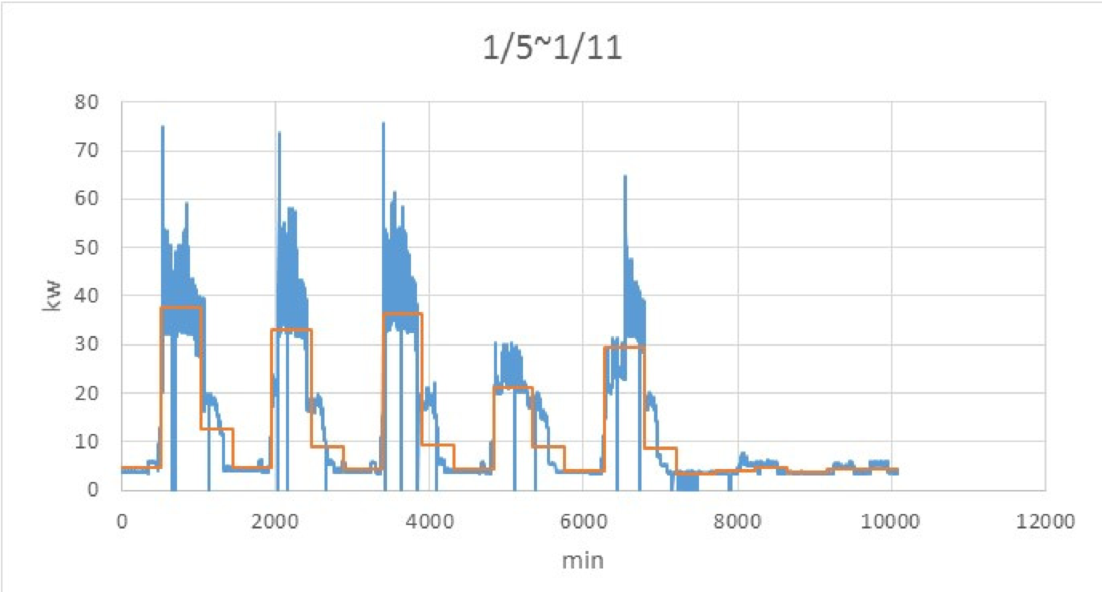

Figure S5. Measured energy usage data of iEN demo site: Store.

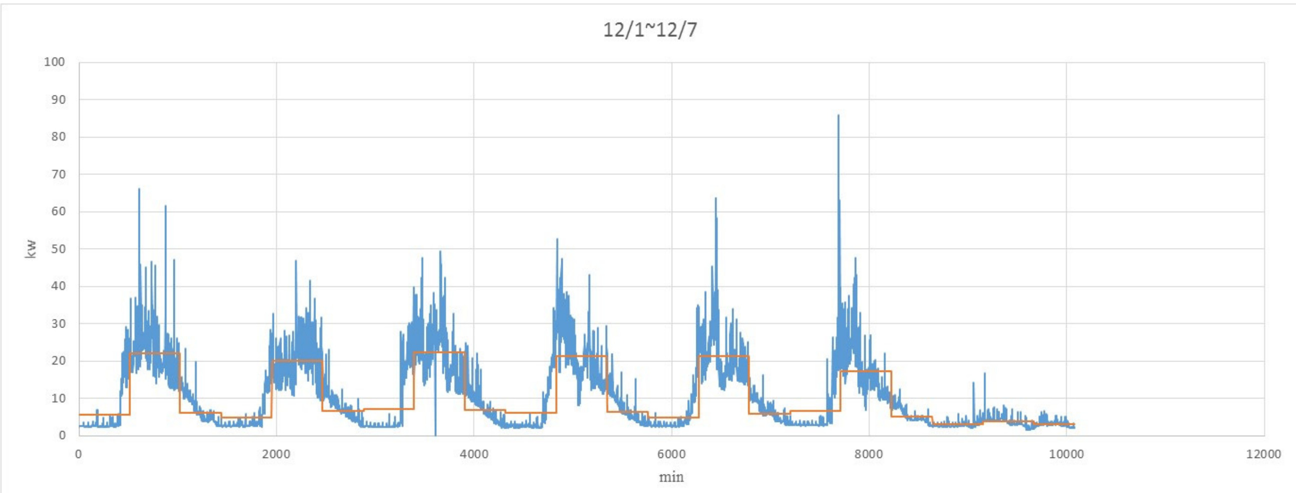

Figure S6. Measured energy usage data of iEN demo site: Office package air conditioning.

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