A prototype tool for automatically giving energy saving advice based on smart meter data

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Abstract

As many countries and regions have started large-scale deployment of smart meters, there is a growing amount of data on electricity use available for energy efficiency services. We have developed a novel tool that, based on smart meter data, automatically generates customised energy saving advice to commercial and industrial customers. This type of audit tool could enormously expand the target of energy audits to almost all small and medium-sized enterprises (SMEs) with smart metering at a low cost per customer. In this paper, we explain the structure of and approaches that we used in our prototype tool, such as fault detection, energy disaggregation, social comparison and benchmarking, and selective visualisation. We also show test case results for the tool by using smart meter data from 35 public buildings in Japan.

Introduction

In this paper, we develop a tool that generates energy saving advice for small- and medium-sized enterprises, (SMEs) based on smart meter data. The background to the development is twofold. First, smart meters are being introduced to customers on a large scale in many countries and regions, and consequently there is a growing amount of data on electricity use available for various services. Although a number of applications and services have been proposed, there are few that target energy efficiency services, especially those for commercial and industrial (C&I) customers. There is a need to develop an effective and scalable service for energy efficiency using smart meter data. Second, there is a need to increase energy efficiency in SMEs. Because SMEs account for a large proportion of energy use and economic output in many countries, it is important for them to increase resource efficiency and their competitiveness (Thollander et al. 2015a). Traditionally, an energy audit has been a common method to assist SMEs with energy savings. Energy audit programmes for SMEs have been found to be effective in many countries, such as US, Germany, Sweden and Japan (Anderson & Newell 2004, Fleiter et al. 2012, Thollander et al. 2015b). However, the coverage of those programmes is actually limited. In Japan, for example, the number of SMEs that are covered by public energy audit programmes is considered to be less than 2000 per year, which is only a fraction of more than 3 million SMEs in the country (Kimura & Noda 2010).

Against this background, we have developed a prototype tool that automatically generates customised energy saving advice to C&I customers based solely on electricity smart meter data. Such a tool would greatly expand the target of energy audits to almost all SMEs with smart meters. There are other tools that use more detailed data from Building Energy Management Systems (BEMS) or Factory Energy Management Systems (FEMS) (Djuric & Novakovic 2009), and they may provide more accurate, specific energy advice. However, the number of firms that can use these systems is limited, at least for the near future. In contrast, the number of C&I customers with smart meters will rapidly increase over the next few years. Furthermore, the per-customer cost to develop and implement a tool based on smart meter data would be low because of the large number of customers and the automated process.

The major target for our tool is small- and medium-sized C&I customers, typically consuming less than 500 kW in contract power. In Japan, there are about 50,000 large customers consuming more than 500 kW, 700,000 medium-sized customers consuming 50 to 500 kW, and over 6 million small customers consuming less than 50 kW (FEPC 2013). To approach such a huge number of SMEs, it is essential to automate all or at least part of the energy assessment, which is becoming possible because of the increasing availability of smart meter data.

Obviously, such a tool has certain limitations. Smart meter data, however valuable, is not an adequate source of information to construct an accurate assessment of a firm's energy use. An energy audit requires not only energy demand data but also depth of other information, such as on building systems and equipment and how they are operated; occupancy; and production processes. An energy audit tool based solely on smart meter data would have low accuracy and low resolution, and might not be effective in certain market segments. However, even a "rough" audit can be useful for many SMEs, who seldom have adequate information on efficient energy use. Therefore, we believe the advantage in terms of the cost and scalability of the tool would outweigh the difficulties and limitations on providing accurate, detailed advice.

The paper is structured as follows. The next section reviews existing tools and methods for energy efficiency that use energy demand data, and confirms the novelty of our focus. Then, we explain the approach, structure, and procedures of the tool we developed. This is followed by the test results of the tool when we apply it to 35 public buildings in Japan. In the concluding remarks, we discuss several issues that need to be addressed and call for further work.

Existing tools for energy efficiency using energy demand data

There is a wide range of tools and methods that analyse data from smart meters and other devices, notably energy management systems (EMS). Efforts have focused on using this type of demand data for energy efficiency services in the residential sector, and a number of trials and pilot projects have already been conducted to change household behaviour. These 'feedback trials' are reviewed by Darby (2006), Fischer (2008), EPRI (2009), and Faruqui et al. (2010). There is a variety of methods and types of feedback in those trials in terms of frequency and duration, type of information provided, medium for providing feedback, mode of presentation, inclusion of comparisons with neighbours, and use of additional information and instruments to increase user engagement (Fischer 2008). Feedback can be "direct", where it is provided in real-time by in-home displays or other devices, or "indirect", where it is provided after consumption via mail, email, or enhanced billing (EPRI 2009).

In contrast, there have been few efforts to use smart meter data in the C&I sector. This is not surprising because in those sectors various feedback devices, such as demand monitors and controllers (DMCs) and EMS, have been used in many facilities for years (Lee & Cheng 2016). Because there are many types of these tools, we provide a brief overview of the main types used in the C&I sector, organised according to their features.

Direct or indirect: DMCs, BEMS, and FEMS are all direct feedback tools that display a facility's energy use in real-time. There are also indirect feedback tools, such as the Business Energy Report (BER) by EnerNOC (formerly Pulse Energy, Molinger 2014, Smith 2014) and OPOWER (Stewart 2015), although a BER uses monthly consumption data rather than smart meter data. An advantage of the indirect approach is that it does not require capital investment in displays, although another medium, such as mail or email, is required.

Single data source (smart meter) or multiple data sources: There are some tools, such as DMCs and BERs, which use a single data source, such as a smart meter. In contrast, BEMS and FEMS usually process multiple data streams, including disaggregated energy demand, as well as non-energy data such as temperature, pressure, and equipment operating status. Remote Building Analytics (RBA), which was commercialised by FirstFuel, uses electric meter data as the main data, but also uses building type and address (Shah 2014).

Single site or multiple sites: Although BEMS and FEMS are usually operated within individual facilities, some companies with multiple facilities integrate their EMS so that they can optimise energy use at the whole-company level and perform comparisons and benchmarking among facilities. Utility-run tools can also make comparisons among customers. The BER, similar to the Home Energy Report (HER), is a good example in this regard.

Degree of analysis: Degree of analysis varies greatly among tools and devices. DMCs and many BEMs in the market "visualise" energy use, such as energy consumption trends, energy consumption by end-use equipment, and comparisons between different equipment, locations, and time points (e.g. today vs. yesterday, this year vs. last year). Analyses that are more complex include estimation of equipment efficiency and fault detection and diagnosis (FDD) (Masukawa et al. 2007, 2012; Djuric & Novakovic 2009). RBA uses statistical and data mining techniques and, according to Shah (2014), can provide detailed recommendations that are comparable to those provided by onsite walk-through audits. Analysis is inevitably limited when based solely on smart meter data, although a BER provides comparison with similar enterprises and usage breakdown by end use category.

The review in this section demonstrates that there are no tools or services that provide energy efficiency advice to SMEs by analysing smart meter data. In the next section, we explain the approach and structure of the tool we developed.

Development of a tool for generating advice reports from smart meter data

APPROACH

We aim to develop a tool that automatically generates customised advice on energy use, based on smart meter data for small- and medium-sized C&I customers. This is obviously a great challenge because smart meter data is not an adequate source of information for an accurate, detailed energy audit. However, we still believe it is possible to provide useful, if rough, advice to many SMEs. We used the following four approaches: fault detection and diagnosis (FDD); disaggregation; benchmarking and social comparison; and selective visualisation.

Fault detection and diagnosis

Faults or defects in building systems are defined as deviations in operating performance of a process from its design or target performance (Hyvärinen et al. 1999). Masukawa et al. (2007, 2012) used the concept for energy analysis and defined an "energy fault" as a situation where energy consumption is more than an expected or optimised level owing to incorrect operation of equipment. FDD has been an active area of research in building engineering, including IEA Energy Conservation in Buildings and Community Systems Programme Annexes 25 and 34 (Hyvärinen et al. 1999, Jagpal 2006). Although many of the FDD methodologies require detailed data from BEMS/FEMS (Djuric & Novakovic 2009, Roth et al. 2005), the concept of FDD may still be useful for smart meter data. Even with limited data, we can detect certain energy faults that are commonly observed in similar types of buildings or industries. For example, the maximum electricity demand of a building often occurs over a very short time in a year, which pushes up the demand charges on a typical rate structure. High demand is often caused by faults in operation. A typical example of such a fault is the inappropriate start-up of a heating, ventilation, and air-conditioning (HVAC) system. Figure 1 shows the load curves of a building during some of the highest demands in a year. All of the highest demands occurred between 8:30 and 10:00, which increased the maximum demand of the building in the year by 5 % to 10 %. Typically, steep demand increase observed around the opening time of an office is caused by the inappropriate start-up of the HVAC system, and demand can be levelled by improving the system operation (e.g., ECCJ 2008). From this general knowledge, we assume it is likely that a building exhibiting this pattern has the same fault even without information about its HVAC system or how the system is operated.

Social comparison/benchmarking

Benchmarking energy performance is an effective method to promote efficient use of energy (Li et al. 2014). Benchmarking is important because it can provide a reference point. If a facility consumes more energy than other similar facilities, it might indicate the potential to save energy. Energy use intensity (EUI) in kWh or MJ per square meter is a common index to benchmark energy efficiency at the whole-building level. Benchmarking specific aspects of energy use in a building is also possible. One example from Japan is benchmarking energy saving efforts during lunchtime. In Japan, the electricity demand during lunchtime is more than 10 % lower than demand during other working hours, both at the grid level and at the individual facility level (Figure 1), mostly because lighting and other energy consuming equipment is switched off (Meier et al. 2015). If an average office saves 15 % but your office only saves 5 %, then your office may be able to reduce energy use by another 10 percentage points with modest effort. Of course, it is not be clear whether this is feasible unless more information about the type of business, operating hours, and lighting systems of the office is available. However, it is still important to inform the user about the deviation from the average and recommend extra measures.

Comparison with other users is important also because it can stimulate a sense of competition, and thus induce (or "nudge") behavioural change (Thaler & Sanstein 2008). A typical example is the HER, a service started by OPOWER. Large-scale experiments on HERs confirmed that comparing household energy use with that of neighbours results in energy savings (Allcott 2011). A similar approach, the BER, is also being tested for the commercial sector (Smith 2014, Molinger 2014, Stewart 2015). Therefore, comparing EUI or energy savings during lunchtime could be effective information for promoting energy saving in companies.

Disaggregation

Energy disaggregation is extracting end-use data from an aggregate, or whole-building, energy signal, by using statistical approaches (Armel et al. 2013). Disaggregated energy use is important information because understanding which equipment consumes how much energy is fundamental for proper energy management. SMEs seldom have a good idea of the breakdown of their energy use, so this information alone may surprise customers, who have typical responses like "Wow, 50 % of our demand is from air-conditioning?" leading to increased attention and action toward equipment with high rates of consumption. Although it is difficult to obtain a detailed, accurate disaggregation from hourly or 30-minute interval demand data, it is still possible to use regression analysis to disaggregate energy use into HVAC demand, which is correlated with outdoor temperature, base demand, which is the minimum demand throughout the year, and other demand. Further disaggregation is possible if we assume that the building has the same demand composition as in an average or typical building in the same type of industry. The accuracy of such disaggregation may be low, but it could still be useful for SMEs.

Selective visualisation

Smart meters are a useful source of data that can be analysed in various ways to improve understanding of a customer's energy use. However, it is not a good strategy to provide customers with many graphs and analysis results. Most people in SMEs are not familiar with energy and may not want to be presented with complicated graphs, such as scatter charts. Even when they understand the meaning of a graph, it might still be difficult for them to derive clear, actionable suggestions from it.

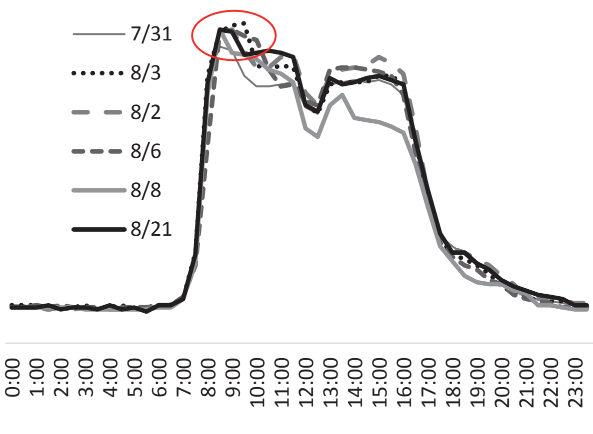


Figure 1. Demand curves of an office building at the times of highest observed demand in a year. An energy fault in the start-up of the HVAC system in the morning can be seen (circle).

Therefore, it is important to select a small number of important graphs and explain what customers should understand from the graphs. For example, the trend in electricity consumption per month would be useful only when it is much larger than that in the same month of the previous year. Similarly, daily comparison of energy use might be worth showing only when, for example, some of the highest demand in a year is observed on a certain day of the week. This selective approach would avoid data overload and improve the focus of the customer on important aspects of energy use.

STRUCTURE AND PROCEDURE

The basic structure of the prototype tool we have developed is presented in Figure 2. The core of the tool is a set of "advices" that we prepare in advance based on the four approaches described above. An advice comprises of a graph constructed from the analysis of smart meter data and some texts to explain the graph and recommend actions. By using the smart meter data of a firm, the tool evaluates the relative importance of each advice for each firm and then selects and orders of advices according to importance. Disaggregation and estimation of operating days are implemented as pre-treatment processes because their results are used when evaluating some of the advices.

Pre-treatment

Disaggregation of energy use and working/non-working day estimation are implemented prior to the advice evaluation process. It is necessary to estimate working/non-working days to improve the accuracy of the disaggregation. For this estimation, we use a daily pattern filtering method (Miller et al. 2015). Each 6-hour period (0–6 am, 6–12 am, 12–6 pm, and 6–12 pm) is scored as either 1, 2, or 3 points depending on the relative level of electricity consumption in each timeslot. If the sum of the points in a single day is 6 or more, then the day is determined as a working day. If the sum is 5 or less, the day is determined as non-working.

For disaggregation, we use a simplified difference method (Yoshida et al. 2015, Mukai et al. 2016) rather than regression analysis using temperature data. This is because the estimated shares of HVAC demand by regression analysis for sample buildings were much smaller than typical shares of HVAC demand, such as those in ANRE (2011). The simplified difference method also has the advantage that it requires fewer computational resources than regression analysis. In this method, the non-HVAC demand is estimated as the average hourly electricity demand in a month with the minimum electricity consumption, whereas the HVAC demand is estimated as the total net hourly electricity demand for non-HVAC demand. In addition, we also estimate electricity demand for lighting by simply multiplying the non-HVAC demand with the typical share of lighting demand in each category of building/industry, as shown in ANRE (2011), for example. The accuracy of this disaggregation method has not been verified by monitoring data, so the results may have low reliability.

Advices

Following the four approaches explained above, we prepared 12 advices (Table 1). Advice no. 1 is about the energy fault in Figure 1. The graph for no. 1 shows demand curves for the 7 days when the 5 hours with the highest demand in the year were observed. We use 5 hours because we assume that 5 hours per year would be short enough for workers to focus on demand reduction without serious adverse effects on the business and comfort. When many of the highest demand periods occur at a certain time, for example, 8:00 to 9:00 in this case, the time is highlighted. Advice no. 2 notifies the seasons when maximum demand occurs. The graph highlights certain periods when the maximum daily demand tends to be especially high in a year.

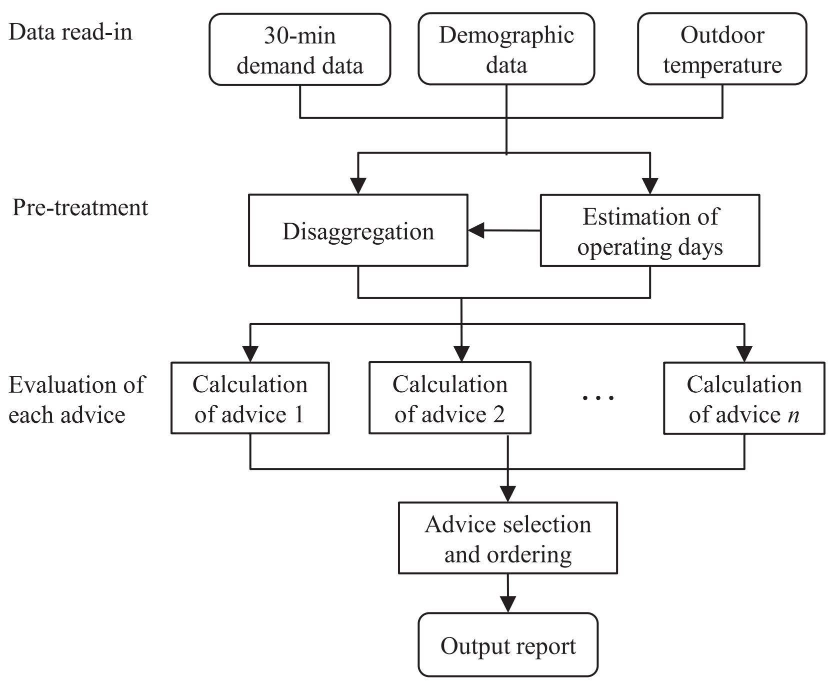
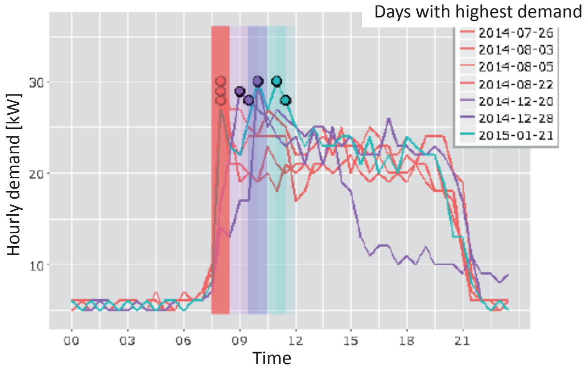
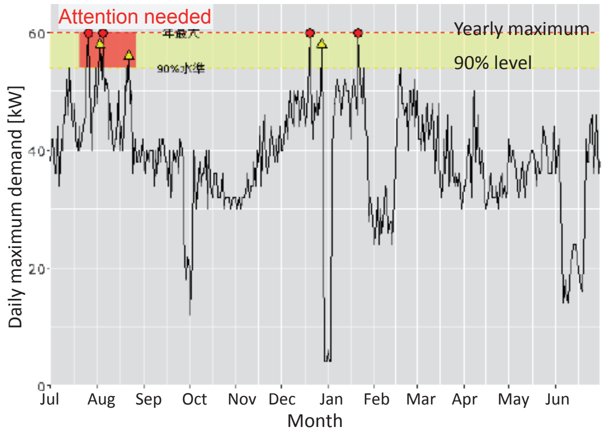
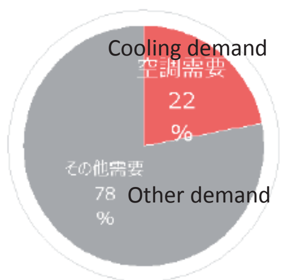


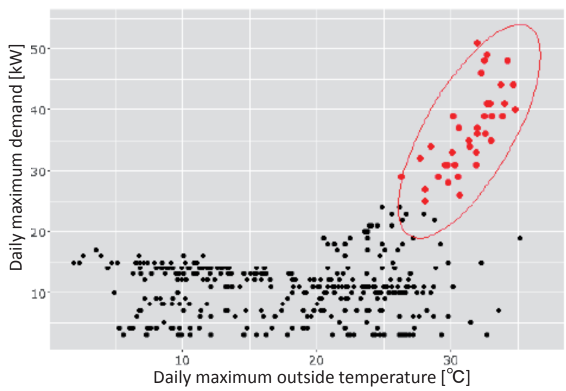
Figure 2. Procedure to generate an advice report.

Table 1. Energy efficiency advice.

<table>
<tr>
<td>No. 1. Hourly demand in days with highest demands in a year


"The maximum demand was increased by 5 % during the highest 5 hours. It could be reduced by improving the start up of the HVAC system in the morning."</td>
<td>No. 2. Trend of maximum daily demand


"The maximum demand in a year often occurs in summer, especially in August. Be careful not to increase your maximum demand in this period."</td>
</tr>
<tr>
<td>No. 3. Disaggregation of energy use: HVAC system


[% of kWh in summer]
"Air-conditioning consumed 22 % of the total electricity consumption in summer 2015. This can be prevented by measures such as changing the HVAC temperature setting and shortening operation hours."</td>
<td>No. 4. Correlation with outdoor temperature


"The maximum demand increases as it becomes hotter. This can be prevented by operational improvement or by renewal of your HVAC system, if it is old."</td>
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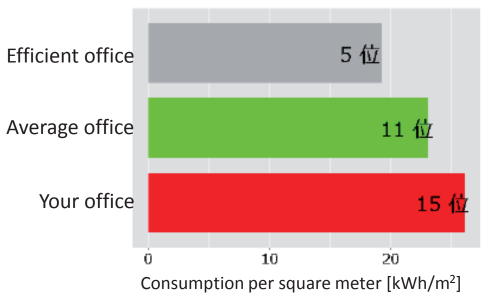
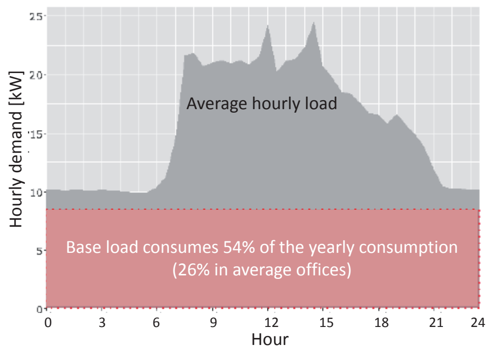
<tr>
<td>No. 5. Benchmarking of consumption per square meter


"Your office consumed more than similar offices in your city in 2015, and ranked 21st out of 25. If you reduce consumption per square meter to the average level, it will save 40 % of your total consumption."</td>
<td>No. 6. Disaggregation of energy use: base load


"Base load consumes 54 % of the total consumption in 2015, which is larger than the average (26 %). Investigate which equipment is working during the night and non-working days and switch off unnecessary loads such as lighting."</td>
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</table>

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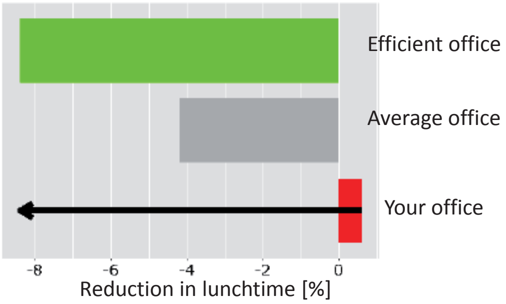
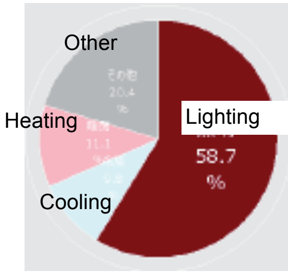
No. 7. Benchmarking of energy savings in lunchtime



"Your office did not save as much electricity during lunchtime as similar offices in your city did in 2015. If you save as much as the average office does, it will save 20,000 JPY a year."

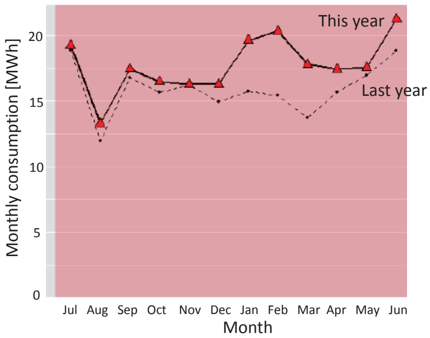
No. 8. Disaggregation of energy use: lightings



[% of kWh in a year]

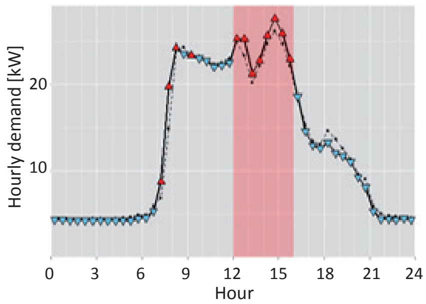
"Lighting accounted for 59 % of total electricity consumption in 2015. This can be saved by reducing lamps and switching to LED lighting."

No. 9. Comparison of monthly consumption with last year



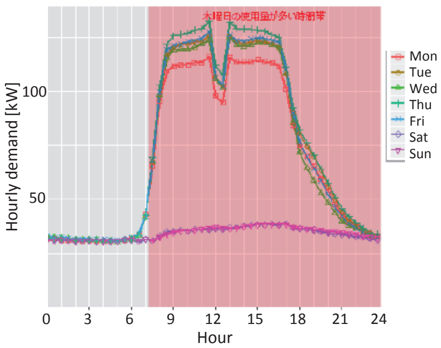
"Consumption in the last 12 months was 12 % larger than a year ago. Look for reasons why it increased."

No. 10. Comparison of hourly demand with last year



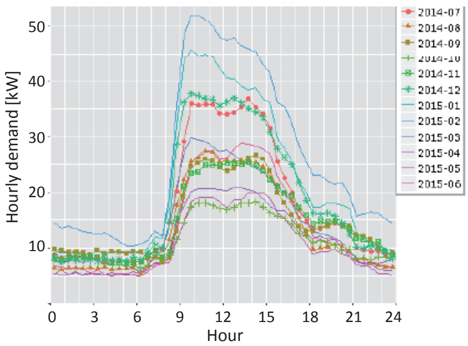
"Consumption in the highlighted hours, 12:00 to 16:00, was 4 % larger than a year ago. Look for reasons why it increased."

No. 11. Comparison of hourly demand of each day of the week



"Consumption on Thursday tends to be 4 % larger than on Tuesday, the second largest day."

No. 12. Comparison of hourly demand of each month



"Consumption in February was 21 % larger than that in January, the second largest month in 2015."

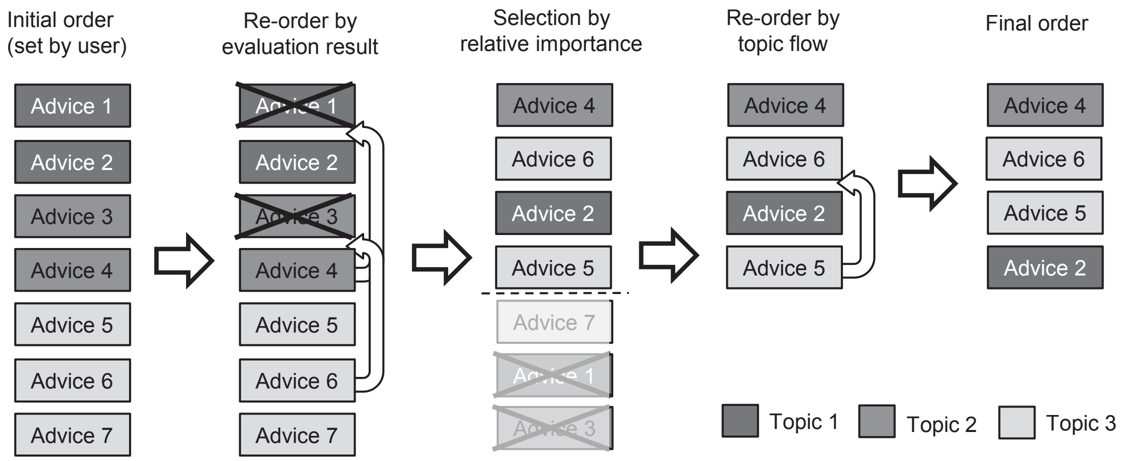


Figure 3. Advice selection and ordering procedure.

Advice nos. 3, 6, and 8 are about disaggregation, and emphasise how large the electricity demand for each end-use is. Advice no. 4 accompanies advice no. 3 to improve understanding of the relationship between demand and weather. Advice nos. 5 and 7 are benchmarking of energy consumption per square meter and energy savings at lunchtime, respectively, within the same category of building, such as offices, retail stores, and schools. Advices nos. 9 to 12 are all visualisations of electricity use of the building, each of which highlights important trends or patterns that are worthy of attention.

Each advice contains text that explains how to understand the graph and what kind of measures or actions to take. Because it is difficult to specify or customise energy saving measures on the basis of analysing smart data alone, in many cases actions are presented as general guidance and are not customised for each building. This also relates to the difficulty of quantifying the energy saving potential from an engineering point of view. Therefore, the energy saving potential presented is based on either comparison with average/energy-efficient competitors or on a simple calculation from our assumptions (e.g., reducing HVAC demand by 10 % will save 10,000 EUR).

Table 1 suggests that some of the advices are not always relevant to a firm and are not worth reporting, which is why the advice evaluation and selection explained below is important. In addition, advices should be modified, added, or deleted according to the characteristics of the targeted population. The primary target of the prototype tool is commercial buildings.

Advice selection and ordering

In this prototype tool, we select the four most important advices to focus customers' attention and avoid information overload. The procedure is presented in Figure 3. First, the user of the tool sets an initial order (or default ranking). The default ranking appears as the advice no. in Table 1. The tool evaluates the importance of each advice. If an advice is evaluated as relevant for the customer, it is given a higher order (advice nos. 4 and 6 in Figure 3). If an advice is evaluated as not relevant, it is deleted (advice nos. 1 and 3 in Figure 3). For instance, if the share of electricity consumption of a HVAC system is larger than a pre-set threshold (e.g., 30 %), advice no. 3 in Table 1 is given a higher order, but if it is smaller than the threshold then it is deleted from the selection. This evaluation is conducted independently for each advice without comparing advices. After this re-ordering process, the four highest-ranked advices are selected. The selected advices are re-ordered again so that advices that belong to the same topic are not separated (advice nos. 5 and 6 in Figure 3) to allow readers to understand it more easily. A topic is a category that includes several advices. For example, advices about the maximum demand in summer/winter (advice nos. 1–4 in Table 1) should appear consecutively. The same is true for advices for disaggregation (advice nos. 6 and 8), those for comparison with the previous year (advice nos. 9 and 10). In this way, the four advices are re-ordered to arrive at the final order.

Test results for public buildings in Japan

We used our tool presented to generate advice reports automatically based on real demand data from 35 public buildings[1] that are located in a suburban city near Tokyo, Japan. The buildings are all owned by the city government and have electricity demand data from 2013 to 2015 at 30-minute intervals, and basic demographic data, such as type of building use and floor space. They consist of a city hall, 23 elementary and junior high schools, 10 cultural/social facilities, and a gymnasium. They are all small- and medium-sized facilities with floor areas from 4,000 to 10,000 square metres and maximum electricity demands from 50 to 300 kW. Figure 4 shows trends and patterns in energy use of the buildings, which are typical of similar facilities in Japan. For example, peak demand is either in summer or winter; hourly demand increases in the morning and decreases in the evening, with a small decrease at lunchtime; schools have summer vacation so have lower demand in August; and demand in spring and autumn is the lowest because air-conditioning and heating are not needed during those seasons.

We assume that we mail the advice reports to those buildings in June 2015 so that managers of those buildings can prepare for the summer, which is the peak period for many buildings[2].

1. Although we have not tested it with industrial customers, the prototype tool and its test results for commercial buildings provide useful insights for developing a similar tool for industrial customers.

2. Note that we did not send any reports because this was only a test output. However, we are preparing a small field trial in collaboration with the city government to send reports to some of those buildings and analyse their responses.

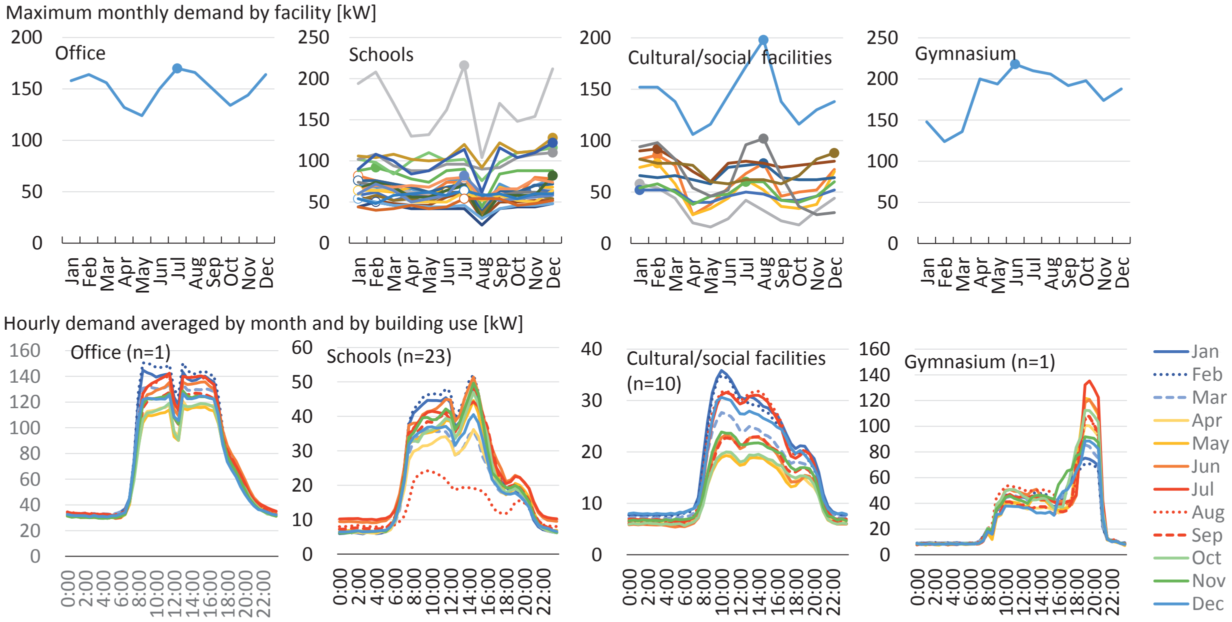


Figure 4. Overview of energy use of the 35 public buildings in 2014.

Therefore, we use two-year data starting from July 2013 to June 2015. A report contains four advices and a simple text summary at the end, all of which is printed on two pages of A4 paper[3]. We generated advice reports for all the buildings automatically. We show two examples of the test results due to space limits.

Figure 5 shows an advice report generated for cultural/social facility A. First, it highlights that the highest demand in the last year was often observed in July and August. The next advice shows the correlation between the maximum daily demand and outside temperature to help customers understand how much the maximum demand might be increased in hot weather. The third advice shows that the highest demand is always observed just after the start time in the morning, implying a fault in air-conditioning start-up settings. This advice is especially important because without this tool and smart meter data there would have been no way to know when and how the maximum demand occurs and what the reason might be. The fourth advice indicates that lighting accounts for a large share of energy consumption, and is followed by a summary of actionable measures and their potential energy and cost savings.

Figure 6 shows an advice report generated for junior high school B. This contains a benchmarking of electricity consumption per square metre per year at the top, because this school consumes more than the average school does. The second advice also shows that lighting accounts for a large share of energy use, which is reasonable for typical energy use in a school that has no air-conditioning and has gas-fuelled heating equipment. This would inform the school that taking measures to improve lighting efficiency would be crucial in reducing total electricity consumption. The load curves for days when the highest demand in a year was observed show that the highest demands were around 15:00 (right-hand side of Figure 6). Because there is no way of knowing what is causing this strange demand peak, the advice just calls for investigation. Our interview with a facility manager suggests that the reason for the demand peak appears to be the use of time-controlled dish dryers in the kitchen. Although it is impossible to infer such a case-contingent reason based on smart meter data, it would still be useful to highlight such an abnormal energy use.

Concluding remarks

Transaction costs are a major barrier to expanding energy efficiency programmes and policies to target SMEs. To reduce transaction costs, automation is crucial, so the automation of energy audits and assessments by using smart metre data is vital for working on this hard-to-reach market segment. This is also important for utility companies, especially in nations or regions with liberalised power markets, because smart meter data is a promising resource for increasing competitiveness and customer satisfaction. The tool presented in this paper is a prototype and has many limitations. Nevertheless, we believe the direction, the approach, and the basic structure of the tool are valuable and can be applied when developing tools that are more sophisticated.

Several issues need to be addressed to improve the tool. First, the content and variety of the advices should be improved to increase accuracy and usefulness for a wider range of customers. We intend to draw on the knowledge of experienced energy auditors to achieve this. Furthermore, while the current version of our tool targets the commercial sector, especially office buildings, it should be expanded to other types of building and sectors. Promising targets would be those with high electricity usage and low variety. Retail stores with refrigerators, such as supermarkets, might be a good example. Although industrial facilities would be a difficult target for this kind of automated tool because of their variety, this sector deserves further research.

3. This format is inspired by HER and BER.

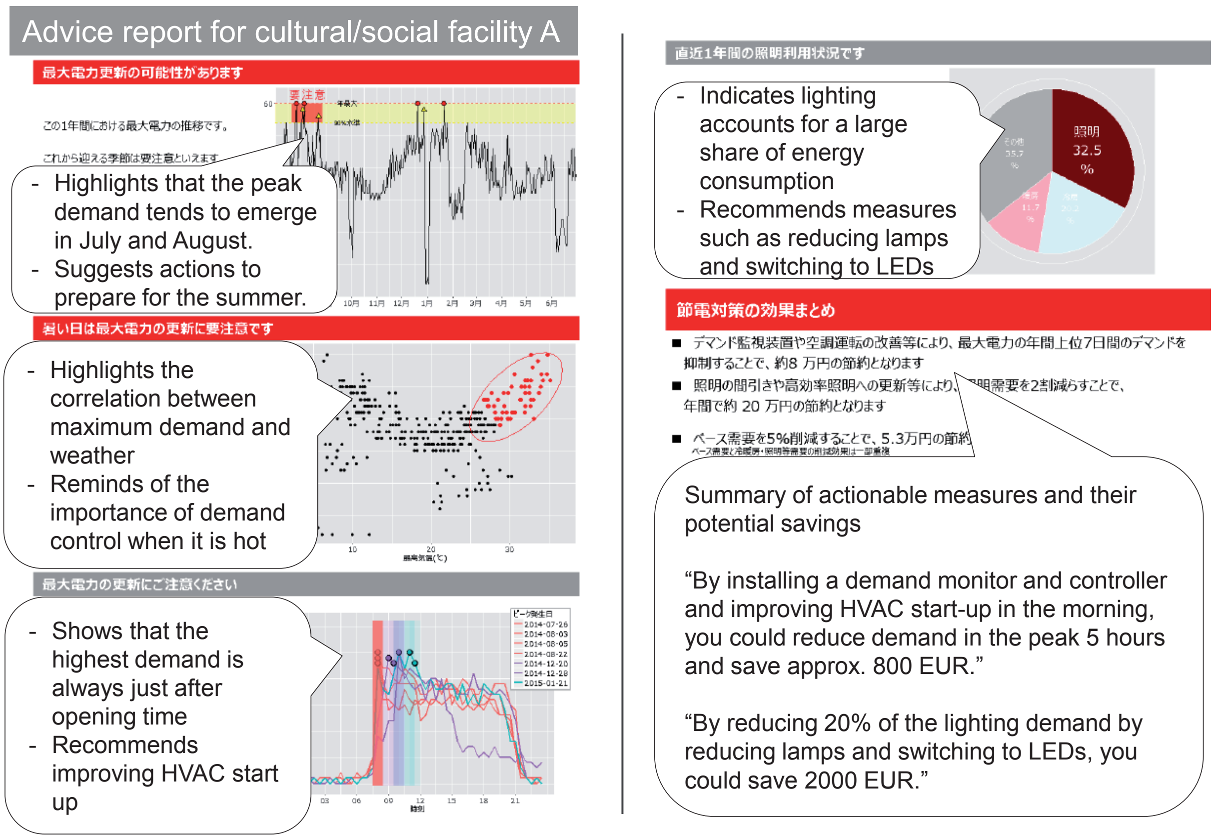


Figure 5. Advice report generated for cultural/social facility A.

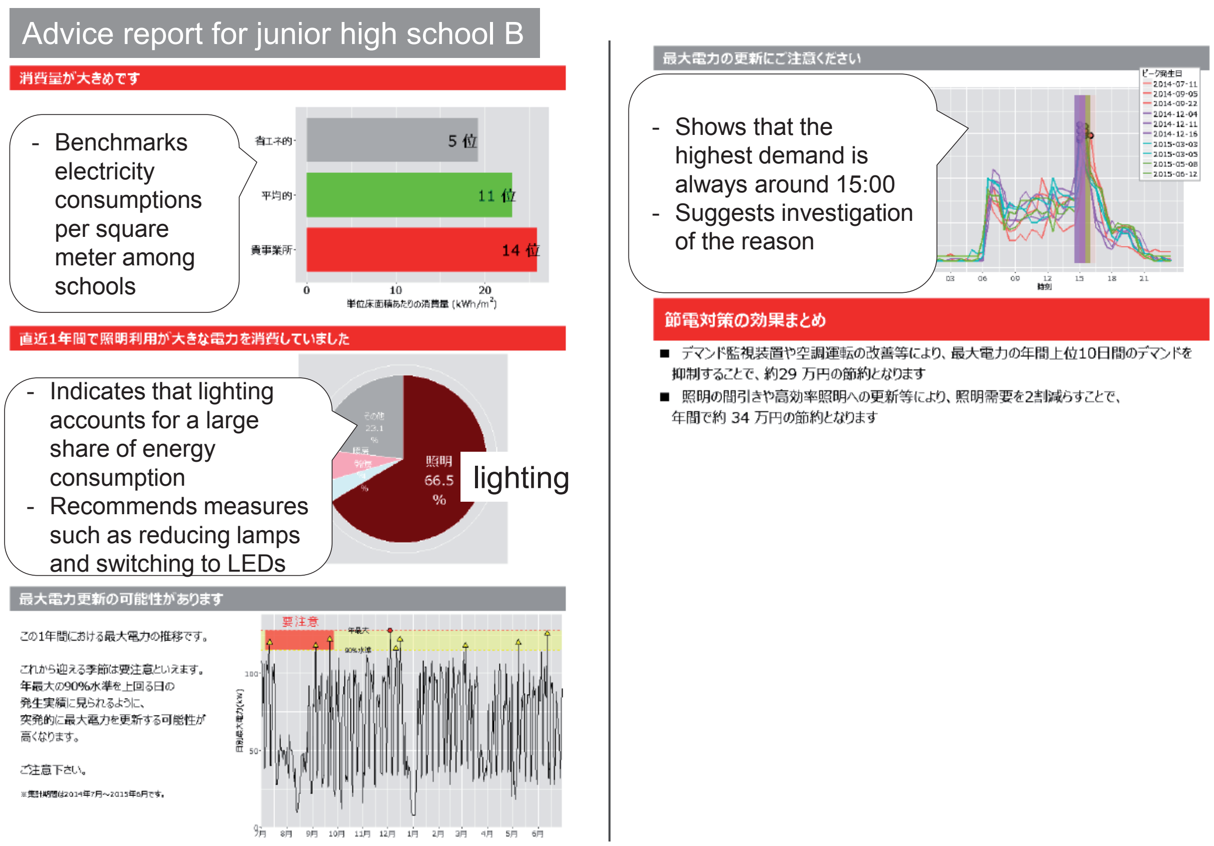


Figure 6. Advice report generated for junior high school B.

Second, we need to test the effectiveness of our advice reports in real-world settings. We should assess whether generated advice reports are useful, persuasive, and attractive to customers, and whether they are accurate from the point of view of engineering and expert opinion, by conducting customer surveys and onsite audits. In addition, we need to quantify the outcome of providing advice reports to customers. Preliminary results from similar pilot projects for BER in the US show that the energy saving effect of BER seems to be, if any, around a few per cent (Smith 2014, Stewart 2015)[4]. This indicates that we need a large-scale trial, probably in collaboration with utility companies, to obtain a statistically meaningful result.

There are also some practical issues, including how to reach the right person in SMEs for a mailed or emailed report to be opened and acted on, and how to collect demographic data such as type of building/industry and floor area when such data is not available. Various trials need to be performed to address these issues.

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4. This is not surprising because the outcome of HER is also estimated to be around 2 % to 5 % savings in well controlled large-scale experiments (Allcott 2011, Allcott & Rogers 2014).

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Endnote

This paper is a shorter version of our full-length report (Komatsu et al. 2016) with some modifications.